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NASA TECHNICAL
MEMORANDUM

NASA TM X-53979

# AN IMPROVED METHOD FOR THIN-FILM THICKNESS MEASUREMENTS

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January 5, 1970



NASA

*George C. Marshall Space Flight Center*
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TECHNICAL REPORT STANDARD TITLE PAGE

| 1. REPORT NO. | 2. GOVERNMENT ACCESSION NO. | 3. RECIPIENT'S CATALOG NO. |
|---|---|---|
| TM X-53979 | | |

| 4. TITLE AND SUBTITLE | 5. REPORT DATE |
|---|---|
| AN IMPROVED METHOD FOR THIN-FILM THICKNESS MEASUREMENTS | January 5, 1970 |
| | 6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S) | 8. PERFORMING ORGANIZATION REPORT # |
| James L. Zurasky and Robert Forsten | |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS | 10. WORK UNIT NO. |
| George C. Marshall Space Flight Center<br>Marshall Space Flight Center, Alabama 35812 | 11. CONTRACT OR GRANT NO. |
| 12. SPONSORING AGENCY NAME AND ADDRESS | 13. TYPE OF REPORT & PERIOD COVERED |
| | Technical Memorandum |
| | 14. SPONSORING AGENCY CODE |

15. SUPPLEMENTARY NOTES

Prepared by the Astrionics Laboratory,
Science and Engineering Directorate

16. ABSTRACT

This report describes an improved method of measuring thin films on metal by interpretation of interference fringes. The essential characteristic of the method is photographing an interference pattern produced by an interferometer; then, this negative is scanned by use of a microdensitometer to determine exact fringe location. Details of the method, expected accuracies, and possible improvements are outlined.

| 17. KEY WORDS | 18. DISTRIBUTION STATEMENT |
|---|---|
| Thin Films<br>Interference Patterns<br>Precision Thickness Measurement | Announce in STAR |

| 19. SECURITY CLASSIF. (of this report) | 20. SECURITY CLASSIF. (of this page) | 21. NO. OF PAGES | 22. PRICE |
|---|---|---|---|
| Unclassified | Unclassified | 15 | $3.00 |

MSFC - Form 3292 (May 1969)

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# AN IMPROVED METHOD FOR THIN-FILM THICKNESS MEASUREMENTS

## SUMMARY


The interferometer has frequently been used to measure thin-film thickness. The procedure is to first etch a channel through the film and then overcoat the sample with aluminum to produce a first surface reflection from both the film and substrate that have been exposed by the etch.

When a wafer is observed under a suitably adjusted interferometer, a series of fringes are produced. The fringes are shifted in position as they cross from the film to the substrate. Determination of this shift yields film thickness in fractions of half-wavelengths of the light used to produce the photograph.

The usual method of interpretation is to photograph some of these fringes, usually three or four, and measure the distance between similar points in the fringe pattern. This method of determination analyzes the fringe pattern over a very large portion of the sample, and the photographic analysis assumes the entire picture is in good focus. Use of this method indicates accuracies of only 50 to 100 Å can be expected.

The present method uses the same basic equipment, but involves the use of a microdensitometer to scan a negative photograph. In this way fringe positions can be determined to a very high degree of accuracy, a smaller area of the sample is analyzed, and only the area of best focus of the photograph is utilized.

## INTRODUCTION

The need for highly accurate measurements of thin-film thicknesses has become a necessity in the fabrication of high quality optical filters and integrated circuits. Precise electrical and optical parameters can be determined only when the thickness is known precisely.

The ellipsometer could be used to determine these properties for dielectrics, but the results are difficult to interpret for metallic films because of the extra unknown parameter introduced by the metal's complex index of refraction. This problem can be averted if one of the three unknowns of the ellipsometer equations can be determined. The complex index of refraction parameters are difficult to measure by any other method, but the thickness parameter can be determined by other procedures.

A conventional method to measure film thickness has been to use an interferometer to produce an interference fringe pattern across an etch line in the film. The step produced in the fringe is a measurement of film thickness. Standard procedure has been to produce a photograph of the fringe pattern that has been magnified many times to produce only a few fringes on the picture. This procedure yields the approximate thickness, but the accuracy is insufficient for use in calculating the other film parameters.

A method to obtain greater accuracy is to photograph a large number of closely spaced fringes. From this negative, that portion which was in best focus is selected. This portion of the film is then scanned with the aid of a microdensitometer, and similar points in the fringe pattern are located. The accuracy of this procedure is dependent upon the precision of the microdensitometer in locating the fringe positions; thus the human fallibility factor is reduced.

## DISCUSSION OF METHOD

Integrated circuit wafers are produced by depositing a thin film of silicon dioxide or other suitable material on a substrate of silicon (Figs. 1 and 2). The thickness of the deposition layer varies from 100 to several thousand angstroms, depending upon the particular circuit parameter being developed. The electrical tolerances of these circuits are dependent upon the accuracy to which the thickness of the deposited layers can be determined. The modification of the Fizeau interference fringe method [1] of thickness determination yields accuracies in the range of ± 10 to 20 Å.

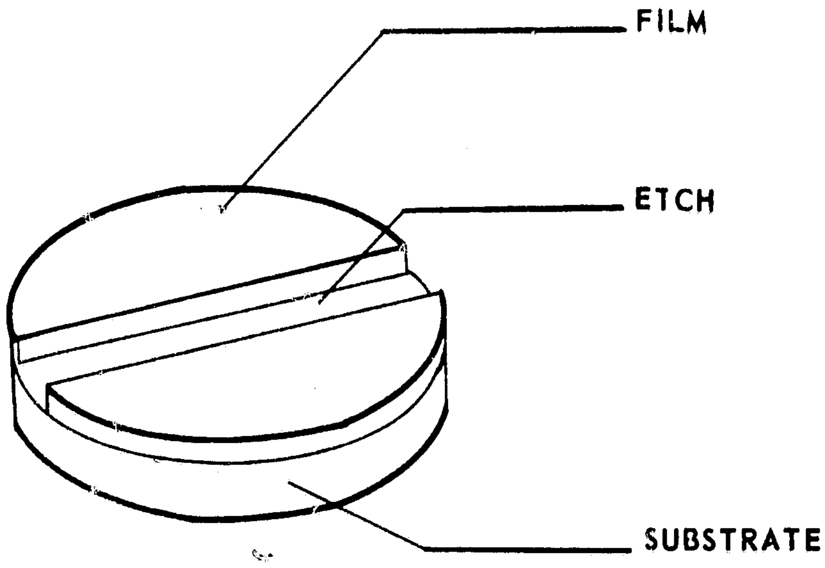


Figure 1. Wafer before aluminization.

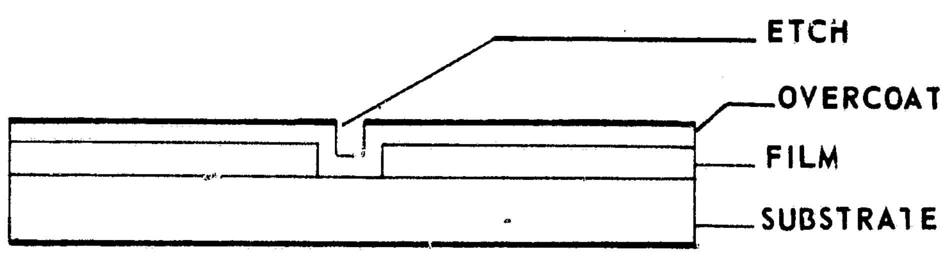


Figure 2. Wafer after aluminization.

After the film has been deposited, a thin etch line is made across the surface to remove the film in this area. The entire surface is then aluminized. This process increases the reflectivity, but more important it overcomes the necessity of compensating for the phase shifts which would occur to the light when reflected from different materials.

The sample is now mounted under an interference objective (Fig. 3) and aligned to produce an interference pattern whose fringes are perpendicular to the etch line (Fig. 4). The interference pattern is produced by the recombination of the reference light beam and light reflected from the sample. Bright fringes occur where the path difference between these beams is an integral number of wavelengths, and dark fringes occur where the path difference is an odd number of half-wavelengths.

For a perfectly flat sample and reflecting mirror in the reference beam, the interference pattern could not be observed if the sample were aligned

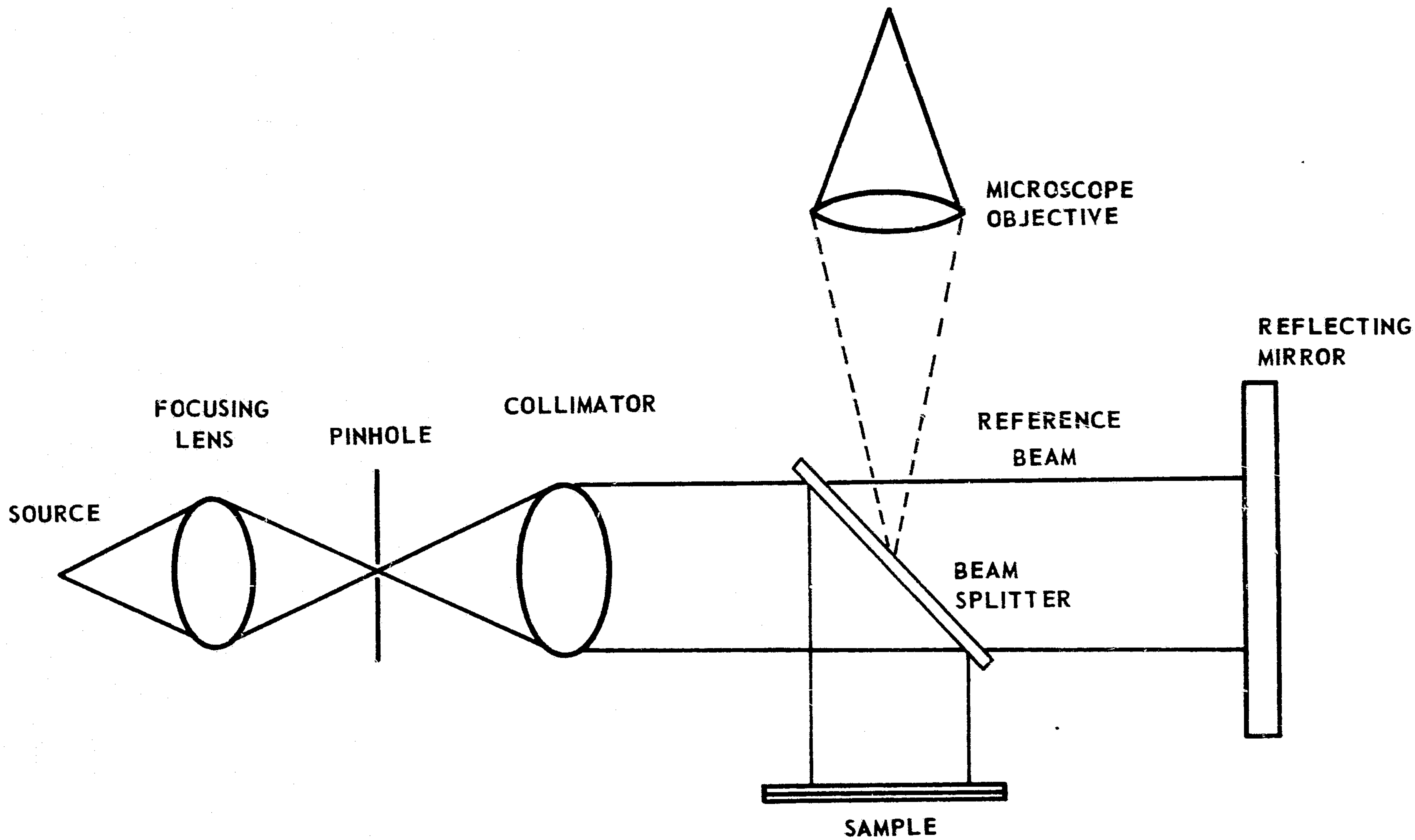


Figure 3. Interference objective.

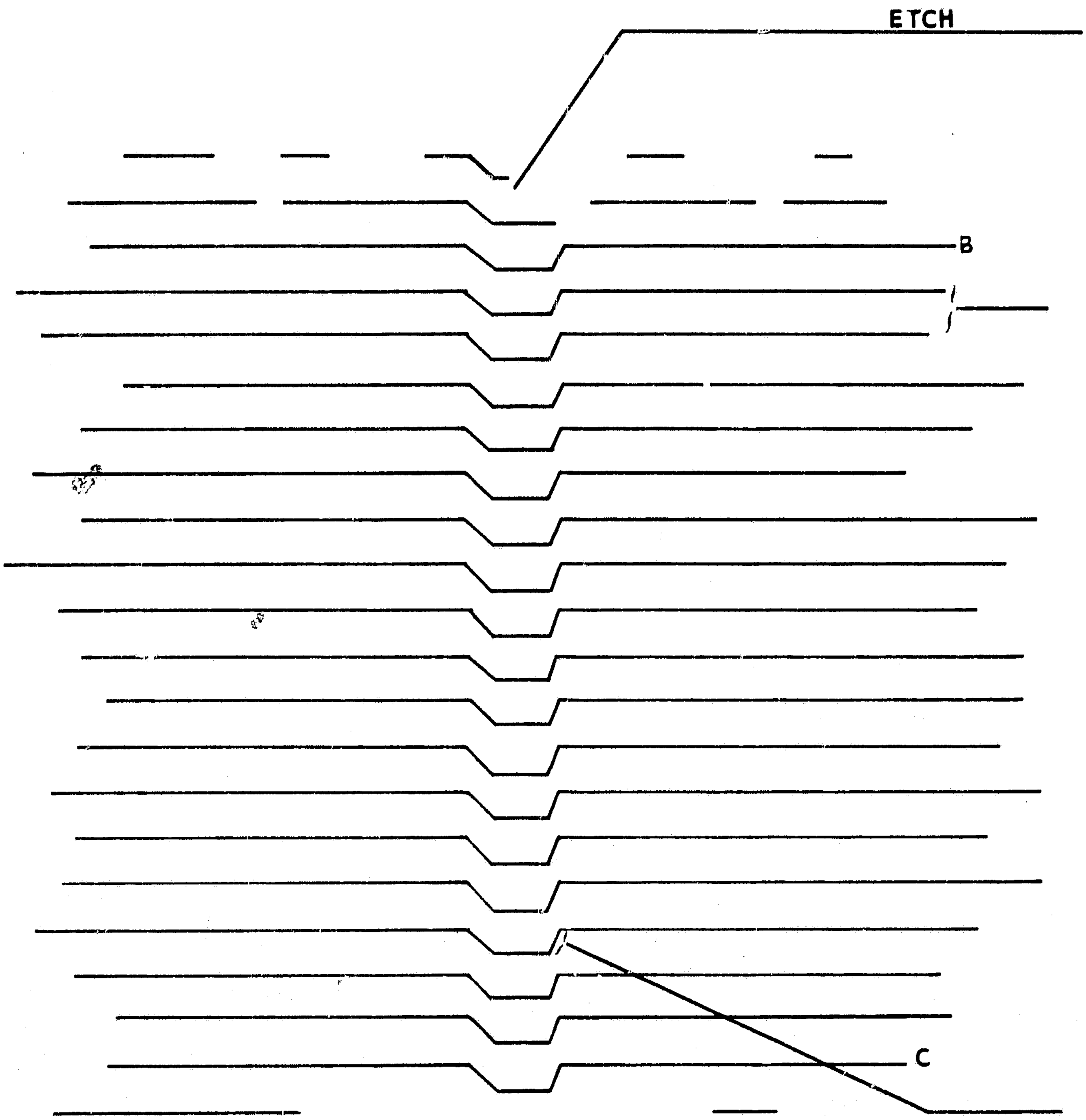


Figure 4. Drawing of a fringe pattern taken from a typical photograph.

perpendicular to the light beam. The sample is therefore tilted with respect to the beam, and an interference pattern is produced when the light recombines.

Analysis of the system's optical paths shows that similar points in the fringe pattern will occur between points on the surface of the sample differing in elevation by a half-wavelength or tilted with respect to the beam in a way that produces an apparent elevation shift of this amount. For the case under study, the pattern is determined by the tilt angle of the sample, with the number of fringes being proportional to the tilt.

These fringes are conveniently observed through a low power (100 ×) microscope. The tilt angle is adjusted to give a large number of fringes in the field of view. This image is then transferred by a set of relay lenses to a film plane where it can be recorded on polaroid type 55P/N film.

The negative from this photograph is scanned by a microdensitometer to determine corresponding points in the interference pattern. As the fringe crosses from the film to the substrate, a noticeable step is observed. The number of microdensitometer units (B) from one fringe to the next is equivalent to the half-wavelength of the light used to produce the pattern.

The number of microdensitometer units (C) from a fringe to its stepped component is determined. From these two values the thickness can be calculated by the following formula:

$$\text{thickness (angstrom units)} = (C/B)\ (\lambda/2)\ \text{(angstrom units)} \qquad (1)$$

If the sample to be measured has a thickness greater than $\lambda/2$, an initial measurement using white light should be used. This procedure produces a set of fringes from which the chromatic order of the fringe pattern can be determined. This measurement yields the correct number of half-wavelengths which must be added to the results of equation (1).

Theory indicates that accuracies of $\pm 10$ Å should be obtainable [2]. Tables 1 and 2 show two sets of data and the results obtained by this method.

The expected precision does not appear to be realizable for several reasons. The principal reasons are (1) local departure from planeness of optically-polished surfaces, (2) local variations in the deposition process, (3) imperfect optical systems, and (4) lack of precision in the photographing process.

TABLE 1. DATA AND RESULTS OBTAINED

| Channel | Edge | $\lambda/2$ | Jump |
|---|---|---|---|
| 150563 | 150258 | 786 | 305 |
| 149777 | 149471 | 785 | 306 |
| 148992 | 148696 | 785 | 296 |
| 148204 | 147904 | 775 | 300 |
| 147429 | 147117 | 786 | 312 |
| 146643 | 146334 | 782 | 309 |
| 145861 | 145555 | 786 | 306 |
| 145075 | 144766 | 787 | 309 |
| 144288 | 143986 | 780 | 302 |
| 143508 | 143203 | 783 | 305 |
| 142725 | 142417 | — | 298 |

Channel - Number of microdensitometer units from one dark fringe to the next in the etch channel.

Edge - Number of microdensitometer units from the dark fringe in the channel to the same fringe across the discontinuity.

$\lambda/2$ - In microdensitometer units $\lambda/2$ is obtained by subtracting channel (1) - channel (2), etc.

Jump - Number of microdensitometer units the fringe is displaced as it crosses the discontinuity.

$\lambda/2 = 2965$ Å
$\lambda/2$ Median = 783.5 Å
Delta $\lambda/2 = 3.7$ Å
Jump Median = 304.4 Å
Delta Jump = 4.92 Å
Thickness = 1813 Å
Delta T = ±18.6 Å

TABLE 2. DATA AND RESULTS OBTAINED

| Channel | Edge | $\lambda/2$ | Jump |
|---|---|---|---|
| 148733 | 148154 | 621 | 579 |
| 148112 | 147531 | 620 | 581 |
| 147492 | 146912 | 621 | 580 |
| 146871 | 147287 | 621 | 584 |
| 146250 | 145670 | 618 | 580 |
| 145632 | 145053 | 620 | 579 |
| 145012 | 144433 | 618 | 579 |
| 144394 | 143813 | 619 | 581 |
| 143775 | 143191 | 623 | 584 |
| 143152 | 142572 | 619 | 580 |
| 142533 | 141949 | — | 584 |

Channel - Number of microdensitometer units from one dark fringe to the next in the etch channel.

Edge - Number of microdensitometer units from the dark fringe in the channel to the same fringe across the discontinuity.

$\lambda/2$ - In microdensitometer units, $\lambda/2$ is obtained by subtracting channel (1) - channel (2), etc.

Jump - Number of microdensitometer units the fringe is displaced as it crosses the discontinuity.
channel (1) - edge (1) = jump, etc.

$\lambda/2$ Median = 620.0 Å
Delta $\lambda/2$ = 1.56 Å
Jump Median = 581.0 Å
Delta Jump = 2.05 Å
Thickness = 2778.5 Å
Delta T = ±9.8 Å

# EXPERIMENTAL LAYOUT

Examples of the samples being measured for integrated circuitry are shown in Figures 1 and 2. An interference objective lens mounted on a microscope is used to produce the interference pattern (Fig. 3). After alignment has been achieved, the image can be transferred by a set of focusing lenses to a film plane.

After development of the film, the negative is scanned by the microdensitometer, which provides a high degree of repeatability in the determination of fringe spacing and fringe shift. These values can then be used to determine film thickness.

# CONCLUSIONS

This measuring technique provides a relatively simple method to reliably measure metallic thin-film thickness. Accuracy of measurement is more precise than the deposition systems being used, and the error factor may be a result of uneven deposition rates, nonflat substrates before the initial deposition, and low resolution film.

Fringe measurements could theoretically be made to a 100-percent accuracy if the interference objective lens system could be mounted as an integral part of the scanning microdensitometer and analyzed directly without going through auxiliary lens systems and the photographing process.

# REFERENCES


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2. Heavens, O. S.: Optical Properties of Thin Solid Films. Academic Press, Inc., Publishers, London, 1955, pp. 110-111.

## APPROVAL

NASA TM X-53979

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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